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(54) **X ray tube anode and tube having same.**

(57) An X-ray tube anode has a thin metal film first layer, e.g. W, for producing hard X-rays. A diamond second layer supports the first layer, conducts heat away from it, and transmits X-rays. The layers usually have a maximum thickness of about the stopping distance of incident electrons. An X-ray tube has such an anode and a heat sink in contact with the layers. The sink can have a beam dump and a transmission mode X-ray window. A normal mode X-ray window is in the tube envelope near the anode.

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X-RAY TUBE ANODE AND TUBE HAVING SAME BACKGROUND OF THE INVENTION

The present invention relates to X-ray tube anodes, and more particularly, to such anodes that efficiently produce a high output hard X-ray flux without suffering thermal damage.

X-ray imaging performance is limited in two fundamental ways by the properties of prior art X-ray tube anodes. First, the total X-ray flux output is limited by the ability of the anode to dissipate heat, and thus the image signal to raise ratio or contrast may not be as high as desired. Second, the spectrum of the emitted X-rays contains too few of high energy (hard) X-ray photons, which are required for imaging of thick or very dense objects. The first problem is due to the fact that a large fraction (typically over 99%) of the energy in the electron beam in a conventional X-ray tube is converted to heat, and only a small fraction is converted to X-rays. This presents a particularly acute problem in microfocus X-ray tubes, which simulate a point source of x-rays (to provide a sharp image) by focusing their electron beam on a very small area of the anode. Thus, the heated area of the anode is essentially only in the very small area, and, therefore, a better means of cooling the operating surface of the anode is required if greater X-ray fluxes are to be obtained. The second problem is caused by the dominant mechanism for converting the energy of an electron beam to X-rays, which is scattering of electrons by the nuclei of atoms in the anode of a X-ray tube. A broad "bremsstrahlung" spectrum results. Electrons which scatter hard in a single collision give up their energy to produce a single, very energetic X-ray photon. Electrons which scatter more gently off several atoms produce numerous softer X-rays.

It is therefore an object of the present invention to provide an anode for an X-ray source that can efficiently provide a hard X-ray flux without suffering thermal damage.

It is another object of the present invention to provide an X-ray tube that uses such an anode.

Summary of the Invention

In brief, these and other objects are achieved by an X-ray tube anode comprising a first means for producing X-rays in response to incident electrons; and a second means, contacting said first means, for supporting said first means and conducting heat away from said first means.

An X-ray tube in accordance with the invention comprises an envelope having first and second ends, an anode disposed proximate said second end, said anode having a first means for producing X-rays in response to incident electrons; and a second means, contacting said first means, for supporting said first means and conducting heat away from said first means.

Brief Description of the Drawing

Figure 1 is a cross-sectional view of an X-ray tube having an anode in accordance with the invention; and

Figures 2(a) and 2(b) are graphs of heat and X-ray production, respectively, as a function of anode thickness.

Detailed Description

The Figure shows a microfocus X-ray tube, generally designated 10, having an envelope 12, typically made of grounded electrically conductive metal with sufficient strength and thickness to withstand a vacuum on the inside thereof and ambient pressure on the outside thereof. A high temperature glass with a grounded conductive interior coating, e.g., Al, can also be used. A grounded envelope or coating is used to provide a return path for stray electrons and for safety. Disposed at a first end 14 of envelope 12 is a cathode 16 coupled to an AC source 18, which typically supplies two to three volts at about one ampere to heat filament cathode 16 so that it will emit electrons. A DC supply could also be used for source 18. It will be understood that the leads connecting cathode 16 to source 18 are insulated from envelope 12 to prevent a short circuit, as are all other leads extending completely through envelope 12. The emitted electrons are provided by a DC source 20 having its positive lead grounded and its negative terminal connected to one of the leads of cathode 16. Source 20 typically provides about 100 at about 1 ma. Although cathode 16 is shown as a directly heated cathode, an indirectly heated one can be used; however, the electrons emitted from a directly heated cathode can be more tightly focused.

The electron beam 20 emitted from cathode 16 passes through an aperture 22 of a control grid 24 disposed proximate cathode 16 and coupled to the negative terminal of DC source 26 having a grounded positive terminal. Source 26 provides about two to three KV and is adjustable so as to provide control of the anode-cathode current and thus the amount of X-rays. Next the electron beam goes through a focusing means or electron lens, e.g., a solenoidal coil 27, coupled to a DC lens power supply 28 that provides current to coil 27. The amount of current is determined by potentiometer 30, which therefore controls the focusing and

spot size on the anode. Although an electromagnetic focusing means has been shown and described, an electrostatic focusing means can be used.

Electron beam 20 finally impinges (is incident) upon a grounded electrically conducting first layer 31a of an anode 32 (described in detail below), which is disposed proximate a second end 33 of envelope 12. It will be appreciated that cathode 16 and the negative terminal of the source 20 can be grounded and the positive terminal of source 20 can be coupled to anode 32 without being grounded. However, the grounded anode configuration, as shown in the drawing and described above, allows for easier replacement of anode 32. Anode 32 further comprises a second layer 31b that contacts and supports first layer 31a and also conducts heat away therefrom. Second layer 31b also contacts a heat sink 38 that conducts heat away from layer 31a and dissipates it. Heat sink 38 has a void 39 in communication with second layer 31b.

A portion of the kinetic energy of beam 20 is converted into X-rays 34a and 34b at layer 31a. X-rays 34a exit tube 10 by way of a normal mode X-ray window 36a disposed in envelope 12 proximate layer 31a. X-rays 34b also go through second layer 31b of anode 32 and then pass through a transmission mode X-ray window 36b disposed in heat sink 38 opposing second layer 31b. Windows 36 are typically made of Be, Al, etc. Some of the electrons in beam 20 do not have their kinetic energy converted to heat, light or X-ray photons. Optionally, these uncoverted electrons 40 are trapped in a beam dump 42 with the aid of a magnetic field. If no dump 42 is used, then they will be collected by window 36b and the upper interior surface of heat sink 38.

X-rays 34 are then incident upon objects (not shown) to be imaged. An X-ray detector (not shown), e.g., scintillator material coupled to a linear photodiode array, detects the X-rays that are transmitted through the object and provides a signal to a computer (not shown) to perform tomography. Instead of using a photodiode array and a computer, a fluoroscope or X-ray sensitive film can be used.

In accordance with one aspect of the invention, first layer 31a comprises a high atomic number and high density material, e.g., Nb, Hf, Ta, Re, Os, Ir, Pt, Au, W, Mo, U, etc., so that a high cross-section is presented to the incident electrons 20. This results in a large X-ray flux. Preferably, the thickness of layer 31a is less than to the stopping distance of the electrons 20 in layer 31a, which distance will vary with the material used in layer 31a and the kinetic energy of electrons 20. A typical value for the thickness of layer 31a is between about 1 to 15 μm. This increases the fraction of high energy (hard) X-rays, since lower energy (soft) X-rays are produced in thicker layers by electrons that have been scattered and slowed down by their penetration of such a thick layer. Such slower electrons also produce a greater percentage of their kinetic energy as heat. Thus the thinness of first layer 31a results in a greater hard X-ray generation efficiency, and also results in the production of less waste heat.

In accordance with another aspect of the invention, second layer 31b is preferably made of a low density, low atomic number, and high thermal conductivity material, e.g., Be, Al, and preferably diamond, the latter either polycrystalline or monocrystalline, so that heat is conducted away from the very small impact area of beam 20 on first layer 31a to heat sink 38. The low density and low atomic number results in layer 31b efficiently transmitting X-rays 34b. If made of diamond, second layer 31b has a typical stopping distance of 45 μm for 100 KEV electrons. This is a typical maximum thickness for layer 31b in order to avoid excessive heat generation therein due to the kinetic energy of the unconverted electrons 40 passing therethrough, although greater thicknesses can be used. Second layer 31b, if made of diamond, can be formed on first layer 31a by chemical vapor deposition. Other materials can be deposited by such known techniques as electroplating, sputtering or electroless deposition. If it is not desired to use transmission mode X-rays 34b for imaging, then second layer 31b need not have a low density or a low atomic number. In such a case, other high thermal conductivity materials, e.g., Cu and Ag, can be added to the list of materials used for second layer 31b.

This anode design offers enhanced performance because it operates in the most favorable portions of the heat production and X-ray production as a function of the thickness of layer 31a relationships. These relationships are respectively illustrated in Figures 2(a) and 2(b).

As shown in Figure 2(b), X-rays are most efficiently generated by a monochromic electron beam 20 of high energy. This is the characteristic of the tube's electron beam 20 when it first contacts the X-ray generating anode layer 31a. As electron beam 20 penetrates into the material of layer 31a, scattering and absorption processes lower the average energy of beam 20 and change it from a monoenergetic beam to a spectrum of electron energies, all lower than the incident energy at the lower surface of layer 31a as viewed in Figure 1. This less energetic beam is a less efficient generator of X-rays. Thus, the largest quantity of useful, hard X-rays are generated near the lower surface of layer 31a.

As shown in Figure 2(a), the loss of average beam 20 energy with thickness of layer 31a has a

similar effect on heat production. At the lower surface of layer 31a, many electrons penetrate the anode layer 31a without scattering. As the beam 20 goes deeper in the anode layer 31a and reaches a lower average energy, the probability of stopping and depositing all of its remaining energy increases. Thus the heat production as a function of the thickness of layer 31a reaches a maximum 48 above the lower surface of the anode layer 31a.

This invention preferably uses anode layers 31a which are thin compared to the average stopping distance of the electron beam in the material of the anode layer 31a. These thin film anodes, illustrated as the dotted lines 50 in Figures 2(a) and 2(b), interact with the electron beam 20 only in the region where the best achievable X-ray output to heat production ratio is in effect. This accounts for the performance advantage of this design.

It will be appreciated that the present invention can also be used with a conventional (non-microfocus) X-ray tube. In particular, it can be used with a rotating anode X-ray tube, wherein the rotating anode comprises a heat sink made of, e.g., Cu, with bevelled edges. Anode 32 is normally disposed only on the bevelled edges.

Claims

1. An X-ray tube anode comprising:
   a first means for producing X-rays in response to incident electrons; and
   a second means, contacting said first means, for supporting said first means and conducting heat away from said first means.

2. The X-ray tube anode of claim 1 wherein said first means comprises a high atomic number and high density first layer disposed on said first layer.

3. The anode of claim 2 wherein said first layer comprises an element selected from the group consisting of Nb, Mo, Hf, Ta, W, Re, Os, Ir, Pt, Au, or U.

4. The anode of claim 3 wherein said element comprises W.

5. The anode of claim 2 wherein said first layer has a maximum thickness less than or about equal to the stopping distance of said incident electrons in said first layer.

6. The anode of claim 2 wherein said first layer has a thickness between about 1 to 15 μm.

7. The X-ray tube anode of claim 1 wherein said second means comprises a high thermal conductivity second layer.

8. The anode of claim 7 wherein said second layer comprises an element selected from the group consisting of Be, Al, Cu, Ag, or diamond.

9. The anode of claim 8 wherein said element comprises diamond.

10. The anode of claim 9 wherein said diamond is monocrystalline.

11. The anode of claim 9 wherein said diamond is polycrystalline.

12. The anode of claim 7 wherein said second layer has a maximum thickness of about 45 μm.

13. The anode of claim 7 wherein said second layer has a maximum thickness about equal to the stopping distance of said incident electrons. 14. The anode of claim 7 wherein said second layer comprises a low atomic number and low density material.

14. An X-ray tube comprising an envelope having first and second ends, an anode disposed proximate said second end, said anode comprising:
    a first means for producing X-rays in response to incident electrons; and
    a second means, contacting said first means, for supporting said first means and conducting heat away from said first means.

15. The tube of claim 15 wherein said tube is a microfocus tube comprising an electron beam focusing means.

16. The tube of claim 16 wherein said focusing means comprises an electromagnetic focusing means.

17. The tube of claim 15 further comprising a heat sink disposed in contact with said second means.

18. The tube of claim 18 wherein said heat sink comprises a beam dump.

19. The tube of claim 15 wherein said heat sink comprises a transmission mode X-ray window disposed opposing said second means.

20. The tube of claim 15 wherein said envelope has a normal mode X-ray window disposed

adjacent said first means.

21. The tube of claim 15 further comprising a cathode disposed proximate said first end, and a control grid disposed adjacent said cathode.

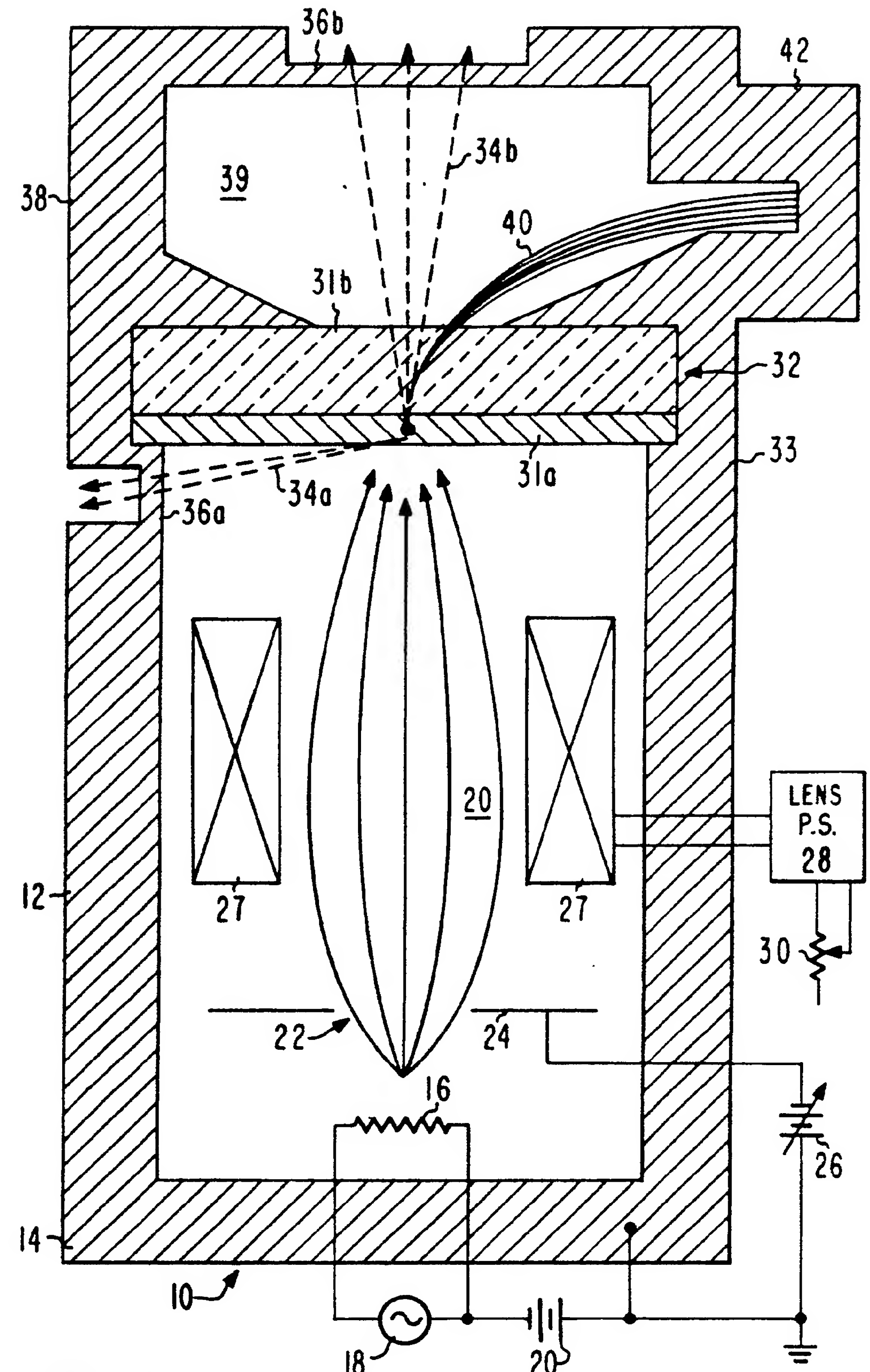
36b
42
34b
39
38
40
31b
32
33
31a
34a
36a
20
LENS
P.S.
28
12
27
27
30
22
24
16
26
14
10
18
20

Fig. 1

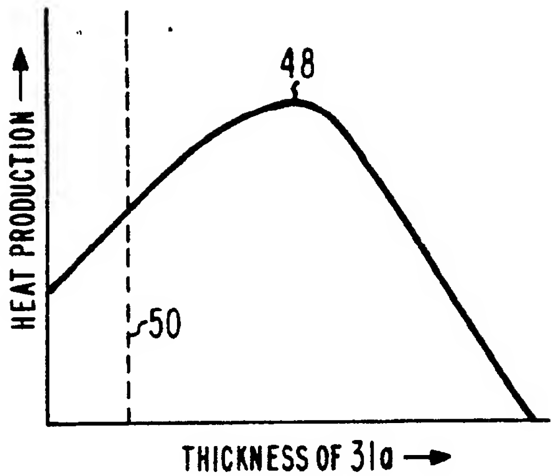
HEAT PRODUCTION
48
50
THICKNESS OF 31a

Fig. 2(a)

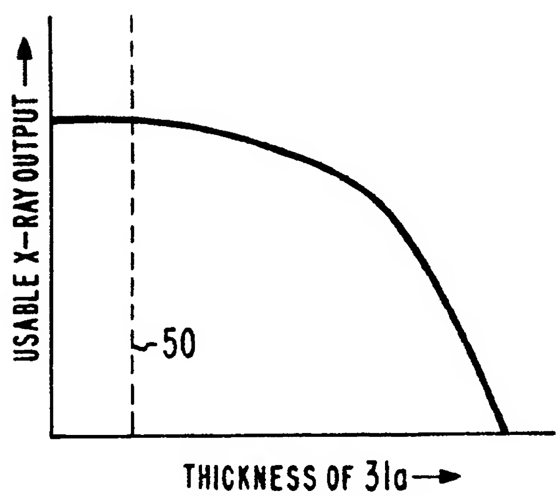
USABLE X-RAY OUTPUT
50
THICKNESS OF 31a

Fig. 2(b)